

Appendix 1. Glossary of Groundwater Hydrology and Modeling Terms

Absorption - dissolving or mixing of a substance in gaseous, liquid or solid form with groundwater.

Adsorption - adherence of molecules in solution to the surface of solids.

Adsorption Isotherm - the graphical representation of the relationship between the solute concentration and the mass of the solute species adsorbed on the aquifer sediment or rock

Advection - the process by which solutes are transported by moving groundwater. This is also called convective transport.

Analytical Model - a mathematical model generally assuming homogeneous aquifer properties, uniform flow direction and hydraulic gradient, uniform aquifer thickness, with simple upper and lower boundaries, and lateral boundaries are placed at an infinite distance.

Anisotropy - the condition of having different values of hydraulic conductivity (in particular) in different directions in geologic materials. This is especially apparent in fractured bedrock or layered sediment.

Aquifer - a geologic formation, group of formations, or part of a formation that is saturated and is capable of providing a significant quantity of water.

Aquifer, Confined - an aquifer bounded above and below by confining beds in which the hydraulic head is above the top of the aquifer.

Aquifer, Unconfined - an aquifer that has a hydraulic head surface (water table) which in equilibrium with the atmosphere.

Area of influence of a well - the area surrounding a well over which the potentiometric surface has changed as the result of pumping groundwater from or recharging groundwater to an aquifer. Same as Zone of Influence. This is not to be confused with the Capture area of a well.

Base Flow - the part of stream flow that is attributable to long-term discharge of groundwater to the stream. This part of stream flow is not attributable to short-term surface run off, precipitation or snow melt events.

Biodegradation, Aerobic - decomposition of organic matter by microorganisms in the presence of free oxygen. The decomposition end-products are carbon dioxide and water.

Biodegradation, Anaerobic - decomposition of organic matter by microorganisms in the absence or near absence of free oxygen. Other electron acceptors, other than oxygen, are used by bacteria in this decomposition process. The decomposition end-products are enriched in carbon.

Boundary Condition - a mathematical statement specifying the dependent variable (e.g.) hydraulic head or concentration) at the boundaries of the modeled domain which contain the equations of the mathematical model. Examples are Specified Head, Specified Concentration, Specified Flux (flow or mass flux), or Mixed Boundaries.

Calibrated Model - a model for which all residuals between calibration targets and corresponding model outputs, or statistics computed from residuals, are less than pre-set acceptable values.

Calibration - the process of refining the model representation of the hydrogeologic framework, hydraulic properties, and boundary conditions to achieve a desired degree of correspondence between the model simulations and observations of the groundwater flow system, which includes both measured hydraulic head and flux.

Calibration Target - measured, observed, calculated, or estimated hydraulic heads or groundwater flow rates that a model must reproduce, at least approximately, to be considered calibrated.

Capillary Fringe - the best region of the vadose zone comprising sediments that are saturated, or nearly saturated, near the water table, gradually decreasing in water content with increasing elevation above the water table.

Cell - also called element, a distinct one-two-or three dimensional model unit representing a discrete portion of a physical system with uniform properties assigned to it.

Code Selection - the process of choosing the appropriate computer code, algorithm, or other analysis technique capable of simulating those characteristics of the physical system required to fulfill the modeling project's objective(s).

Computer Code (computer program) - the assembly of numerical techniques, bookkeeping, and control language that represents the model from acceptance of input data and instructions to delivery of output. Examples: MODFLOW, BIOSCREEN, MT3d, etc.

Concentration Gradient - the rate of change in solute concentration per unit distance at a given point and in a given direction.

Conceptualization Error - a modeling error where model formulation is based on incorrect or insufficient understanding of the modeled system.

Conceptual Model - an interpretation of the characteristics and dynamics of an aquifer system which is based on an examination of all available hydrogeological data for a modeled area. This includes the external configuration of the system, location and rates of recharge and discharge, location and hydraulic characteristics of natural boundaries, and the directions of groundwater flow throughout the aquifer system.

Cone of Depression - a depression of the potentiometric surface that develops around a well which is being pumped.

Confining Bed (Confining Unit) - a hydrogeologic unit of less permeable material bounding one or more aquifers. Synonymous with aquitard, aquiclude, and aquifuge.

Constant-Head Boundary - see **Specified Head Boundary**.

Constant-Head Node - a location in the discretized groundwater flow model domain (node) where the hydraulic head remains the same over the time period considered; see also specified head.

Contaminant Fate - chemical changes and reactions that change the chemical nature of the contaminant, effectively removing the contaminant from the subsurface hydrologic system.

Contaminant Transport Model - a model describing the movement of contaminants in the environment.

Contaminant Transport Velocity - is the rate in which contamination moves through an aquifer.

Degradation Constant - term used to address the decay of contaminant concentration due to factors other than dispersion.

Desorption - all processes by which chemicals move from the solid phase and concentrate them in the liquid phase (groundwater).

Diffusion - process by which ions or molecules move in a random manner, because of their thermal kinetic energy, from areas of high solute concentrations to areas of low concentration in the direction of the solute concentration gradient. Also referred to as molecular diffusion.

Diffusion Coefficient - a constant of proportionality which relates the mass flux of a solute to the solute concentration gradient.

Discretization - is the process of subdividing the continuous model and/or time domain into discrete segments or cells. Algebraic equations which approximate the governing flow and/or transport equations are written for each segment or cell.

Dispersivity - a scale dependent property of an aquifer that determines the degree to which a dissolved constituent will spread in flowing groundwater. Dispersivity is comprised of three directional components - longitudinal, transverse and vertical.

Dispersion - process by which some of the water molecules and solute molecules travel more rapidly than the average linear velocity and some travel more slowly; spreading of the solute in the direction of the groundwater flow (longitudinal dispersion) or direction perpendicular to groundwater flow (transverse dispersion).

Dispersion Coefficient - (1) a measure of the spreading of a flowing substance due to the nature of the porous medium, with its interconnected channels distributed at random in all directions; (2) the sum of the coefficients of mechanical dispersion and molecular diffusion in a porous medium.

Distribution Coefficient - the quantity of the solute, chemical or radionuclide sorbed by the solid per unit weight of solid divided by the quantity dissolved in the water per unit volume of water.

Drawdown - (1) the vertical distance the potentiometric surface is lowered due to the removal of water from a hydrogeologic unit.

Eh - also known as redox potential. Eh is a numerical measure of the intensity of oxidation or reducing conditions. A positive potential indicates oxidizing conditions and a negative potential indicates reducing conditions.

Elevation Head - that part of hydraulic head which is attributable to the elevation of a measuring point (e.g. mid-point of a well screen) above a given datum (e.g. mean sea level).

Equipotential Line - a line connecting points of equal hydraulic head (potential). A set of such lines provides a contour map of a potentiometric surface.

Field Characterization - a review of historical, on-and off-site, as well as surface and sub-surface data and the collection of new data to meet project objectives; field characterization is a necessary prerequisite to the development of a conceptual model.

Finite Difference Method (FDM) - a discretization technique for solving a partial differential equation (PDE) by (1) replacing the continuous domain of interest by a finite number of regular-spaced mesh-or grid-points (i.e., nodes) representing volume-averaged sub-domain properties; and (2) by approximating the derivatives of the PDE for each of these points using finite differences; the resulting set of linear or nonlinear algebraic equations is solved using direct or interactive matrix solving techniques.

Finite Element Method (FEM) - similar to finite difference method with the exception that (1) the mesh may consist of regular or irregular-spaced grid points which may have irregular shapes; and (2) the PDE is approximated using the method of weighted residuals to obtain a set of algebraic equations. These algebraic equations are solved using direct or iterative matrix solving techniques.

Finite Difference Model - a type of numerical model that uses a mathematical technique called the finite-difference method to obtain an approximate solution to the governing partial differential equation (in space and time).

Finite Element Model - a numerical model that uses a mathematical technique called the finite-element method to obtain an approximate solution to the governing partial differential equation (in space and time).

Flow Path - the subsurface course a water molecule or solute would follow in a given groundwater velocity field.

Flux - the volume of fluid crossing a unit cross-sectional surface area per unit time.

Groundwater - that part of the subsurface water that is in the saturated zone.

Groundwater Basin - a groundwater system that has defined boundaries and may include more than one aquifer of permeable materials, which are capable of furnishing a significant water supply. Note - a basin is normally considered to include the surface area and the permeable materials beneath it. The surface water divide need not coincide with a groundwater divide.

Groundwater Discharge - the water released from the zone of saturation; also the volume of water released.

Groundwater Flow - the movement of water in the zone of saturation.

Groundwater Flow Model - an application of mathematical model to represent a regional or site-specific groundwater flow system.

Ground Flow System - a water saturated aggregate of aquifers and confining units in which water enters and moves and which is bounded by a basal confining unit that does not allow any vertical water movement and by zones of interaction with the earth's surface and with surface water systems. A groundwater flow system has two basic hydraulic functions: it is a reservoir for water storage, and it serves as a conduit transmitting water from recharge to discharge areas. A groundwater flow system may transport dissolved chemical constituents and heat.

Groundwater Modeling Code - the computer code used in groundwater modeling to represent a non unique, simplified mathematical description of the physical framework, geometry, active processes, and boundary conditions present in a reference subsurface hydrologic system.

Head (Total; Hydraulic head) - the height above a datum plane (such as sea level) of the column of water that can be supported by the hydraulic pressure at a given point in a groundwater system. In a well it is the elevation of the height of water in a well above the mid-point of a well screen (Pressure Head) plus the elevation of the mid point of the well screen (Elevation Head).

Head Dependent Boundary - see Mixed Boundary.

Heterogeneity - a characteristic of a medium in which material properties vary from point to point everywhere.

History Matching - Also referred to as Model Verification.

Homogeneity - a characteristic of a medium in which material properties are identical everywhere.

Hydraulic Conductivity - a constant of proportionality which relates the rate of groundwater flow to the hydraulic head gradient. It is a property of the porous media (Intrinsic Permeability) and the density and viscosity of the water moving through the porous media. It is defined as the volume of water at the existing kinematic viscosity that will move in unit time under unit hydraulic gradient through a unit area measured at right angles to the direction of flow. Estimated by, in order of preference, aquifer tests, slug tests, grain size analysis.

Hydraulic Gradient - the change in total hydraulic head per unit distance of flow at a given point and in the direction of groundwater flow.

Hydraulic Head - the height above a datum plane (such as sea level) of the column of water that can be supported by the hydraulic pressure at a given point in a groundwater system. For a well, the hydraulic head is equal to the distance between the water level in the well and the datum plane.

Hydraulic Properties - properties of solid and rock that govern the entrance of water and the capacity to hold, transmit and deliver water, e.g. porosity, effective porosity, specific retention, permeability and direction of maximum and minimum permeability. Synonymous with Hydrologic Properties.

Hydrologic Boundaries - physical boundaries of a hydrologic system.

Hydrologic Unit - geologic strata that can be distinguished on the basis of capacity to yield and transmit fluids. Aquifers and confining units are types of hydrologic units. Boundaries of a hydrologic unit may not necessarily correspond either laterally or vertically to lithostratigraphic formations.

Impermeable Boundary - the conceptual representation of a natural feature such as a fault or depositional contact that places a boundary of significantly less-permeable material laterally adjacent to an aquifer.

Initial Conditions - the specified values for the dependent variable (hydraulic head or solute concentration) at the beginning of the model simulation.

Intrinsic Permeability - a term describing the relative ease with which a porous medium can transmit a liquid under a hydraulic gradient or potential gradient. It is distinguished from hydraulic conductivity in that it is a property of the porous medium alone and is independent of the nature of the liquid or the potential field.

Inverse Method - a method of calibrating a groundwater flow model using a computer code to systematically vary inputs or input parameters to minimize residuals or residual statistics.

Kriging - a geostatistical interpolation procedure for estimating spatial distributions of model inputs from scattered observations.

Leakage - (1) the flow of water from one hydrogeologic unit to another. The leakage may be natural, as through semi-impervious confining layer, or human made, as through an uncased well; (2) the natural loss of water from artificial structures as a result of hydrostatic pressure.

Leaky Aquifer - aquifers, whether artesian or water table, that lose or gain water through adjacent less permeable layers.

Mathematical Model - (a) a set of mathematical equations expressing the physical system and including simplifying assumptions; (b) the representation of a physical system by mathematical expressions from which the behavior of the system can be deduced with known accuracy.

Mixed Boundary - is a linear combination of head and flux at a boundary. An example of a mixed boundary is leakage between a river and an underlying aquifer.

Model - an assembly of concepts in the form of mathematical equations that portray an understanding of a natural phenomenon.

Model Construction - the process of transforming the conceptual model into a parameterized mathematical form; as parameterization requires assumptions regarding spatial and temporal discretization, model construction requires a-priori selection of computer code.

Model Grid - system of connected nodal points superimposed over the problem domain to spatially discretize the problem domain into cells (finite difference method) or elements (finite element method) for the purpose of numerical modeling.

Modeling - the process of formulating a model of a system or process.

Model Input - the constitutive coefficients, system parameters, forcing terms, auxiliary conditions and program control parameters required to apply a computer code to a particular problem.

Modeling Objectives - the purpose(s) of a model application.

Model Verification - in model application: a) the procedure of determining if a (site-specific) model's accuracy and predictive capability lie within acceptable limits of error by tests independent of the calibration data; b) in model application: using the set of parameter values and boundary conditions from a calibrated model to acceptably approximate a second set of field data measured under similar hydrologic conditions. Also referred to as History Matching.

Node (Nodal Point) - in a numerical model, a location in the discretized model domain where a dependent variable (hydraulic head) is computed.

No-Flow Boundary - model boundary which is a Specified Flux Boundary where the assigned flux is equal to zero. Also see Boundary condition.

Numerical Methods - in subsurface fluid flow modeling, a set of procedures used to solve the groundwater flow equations in which the applicable partial differential equations are replaced by a set of algebraic equations written in terms of discrete values of state variables (e.g. hydraulic head) at discrete points in space and time. The most commonly used numerical methods in groundwater models are the finite-difference method, the finite-element method, the boundary element method and the analytic element method.

Numerical Model - in subsurface fluid flow modeling, a mathematical model that uses numerical methods to solve the governing equations of the applicable problem.

Numerical Solution - an approximate solution of a governing (partial) differential equation derived by replacing the continuous governing equation with a set of equations in discrete points of the model's time and space domains.

Over calibration - achieving artificially low residuals by inappropriately adjusting model input parameters without field data to support the adjusted model parameter value.

Output - in subsurface fluid flow modeling, all information that is produced by the computer code.

Parameter - any of a set of physical properties which determine the characteristics or behavior of a system.

Parameter Identification Model (inverse model) - a computer code for determination of selected unknown parameters and stresses in a groundwater system, given that the response of the system to all stresses is known and that information is available regarding certain parameters and stresses.

Partitioning Function - a mathematical relation describing the distribution of a reactive solute between solution and other phases.

Peclet Number - a relationship between the advective and diffusive components of solute transport expressed as the ratio of the product of the average interstitial velocity, times the characteristic length, divided by the coefficient of molecular diffusion; small values indicate diffusion is the dominant transport process, large values indicate advection dominance.

Perched Ground Water - unconfined groundwater separated from an underlying body of ground water by an unsaturated zone.

Percolation - the movement of water through the vadose zone, in contrast to infiltration at the land surface and recharge across the water table.

Piezometric Surface - see Potentiometric Surface

Porosity, Total - the ratio of the volume of void spaces in a rock or sediment to the total volume of the rock or sediment.

Porosity, Effective - (1) the ratio, usually expressed as a percentage, of the total volume of voids to the total volume of the porous medium; (2) the ratio of the volume of the voids of a soil or rock mass that can be drained by gravity to the total volume of the mass; (3) the amount of interconnected pore space and fracture openings available for the transmission of fluids, expressed as the ratio of the volume of interconnected pores and openings to the volume of rock.

Postprocessing - using computer programs to assist in preparing data sets for use with generic simulation codes; may include grid generation, parameter allocation, control parameter selection, and data file formatting.

Pressure head - the head of water at a point in a porous system; negative for unsaturated systems, positive for saturated systems. Quantitatively, it is the water pressure divided by the specific weight of water.

Reaction Path Modeling - a simulation approach to studying the chemical evolution of a (natural) system.

Recharge, Groundwater - the process of water addition to the saturated zone usually from precipitation.

Residual - the difference between the model-computed and field-measured values of a variable, such as hydraulic head or groundwater flow rate, at a specific time and location.

Retardation Factor - is used to simulate the resistance of the contamination to move through the groundwater aquifer. A factor of one (1) represents the least resistance while increasing values show increasing resistance.

Saturated Zone - (1) those parts of the subsurface in which all voids are filled with water under pressure greater than atmospheric; (2) that part of the subsurface beneath the regional water table in which all voids, large and small, are filled with water under pressure greater than atmospheric; (3) means that part of the subsurface beneath the regional water table in which all voids, large and small, are ideally filled with water under pressure greater than atmospheric.

Seepage Face - a physical boundary segment of a groundwater system along which groundwater discharges and which is present when a water table surface ends at the downstream external boundary of a flow domain; along this boundary segment, of which the location of the upper end is a priori unknown, water pressure equals atmospheric pressure and hydraulic head equals elevation head. Commonly referred to as "seeps" or "springs".

Semi-Analytical Model - a mathematical model in which complex analytical solutions are evaluated using approximate techniques, resulting in a solution discrete in either the space or time domain.

Sensitivity - the variation in the value of one or more output variables (such as hydraulic heads) or quantities calculated from the output variables (such as groundwater flow rates) due to

changes in the value of one or more inputs to a groundwater flow model (such as hydraulic properties or boundary conditions).

Sensitivity Analysis - a procedure based on systematic variation of model input values (1) to identify those model input elements that cause the most significant variations in model output; and (2) to quantitatively evaluate the impact of uncertainty in model input on the degree of calibration and on the model's predictive capability.

Simulation - in groundwater modeling, one complete execution of a groundwater modeling computer program, including input and output. Simulation is sometimes also used broadly to refer to the process of modeling in general.

Sink - in subsurface fluid flow modeling, a process whereby, or a feature from which, water is extracted from the groundwater flow system.

Site Characterization - (1) a general term applied to the investigation activities at a specific location that examines natural phenomena and human-induced conditions important to the resolution of environmental, safety and water resources issues; (2) means the program of exploration and research, both in the laboratory and in the field, undertaken to establish the geologic conditions are the ranges of those parameters of a particular site relevant to the program. Site characterization includes geophysical testing, borings, surface excavations, excavation of exploratory shafts, limited subsurface lateral excavations and borings and in situ testing a depth needed to determine the suitability of the site.

Soil Bulk Density - the mass of dry soil per unit bulk soil.

Solubility - the total amount of solute species that will remain indefinitely in a solution maintained at constant temperature and pressure in contact with the solid crystals from which the solutes were derived.

Solute Concentration - the concentration of a chemical species dissolved in groundwater.

Solute Transport Model - application of a model to represent the movement of chemical species dissolved in groundwater.

Sorption - (1) a general term used to encompass the process of absorption and adsorption; (2) all processes which remove solutes from the fluid phase and concentrate them on the solid phase of the medium.

Source - a process, or a feature from which, water, vapor NAPL, solute or heat is added to the groundwater or vadose zone flow system.

Source of Contaminants - the physical location (and spatial extent) of the source contaminating the aquifer; in order to model fate and transport of a contaminant, the characteristics of the contaminant source must be known or assumed.

Source Loading - the rate at which a contaminant is entering the groundwater system at a specific source.

Specific Capacity - the rate of discharge from a well divided by the drawdown of the water level within the well at a specific time since pumping started.

Specific Discharge - the rate of discharge of groundwater per unit area of a porous medium measured at right angle to the direction of groundwater flow. Synonymous with flow velocity, darcian velocity and specified flux.

Specific Storage - the volume of water released from or taken into storage per unit volume of the porous medium per unit change in head.

Specific Yield - the ratio of the volume of water that the saturated rock or soil will yield by gravity to the volume of the rock or soil. In the field, specific yield is generally determined by tests on unconfined aquifers and represents the change that occurs in the volume of water in storage per unit area of unconfined aquifer as the result of a unit change in head. Such a change in storage is produced by draining or filling of pore space and is therefore, mainly dependent on particle size, rate of change of the water table, and time of drainage.

Specified Flux Boundary - a model boundary condition in which the groundwater flux or mass flux is specified; also called fixed or prescribed flux, or Neumann boundary condition.

Specified Concentration Boundary (Constant Concentration) - a boundary at which the solute concentration is specified; also called fix or prescribed concentration, or Dirichlet boundary condition.

Steady State Condition - a condition in which system inputs and outputs are in equilibrium so that there is no net change in the system with time.

Steady State Flow - a characteristic of a groundwater or vadose zone flow system where the magnitude and direction of specific discharge at any point in space are constant in time.

Storage Coefficient - the volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head. For a confined aquifer, the storage coefficient is equal to the product of the specific storage and aquifer thickness. For an unconfined aquifer, the storage coefficient is approximately equal to specific yield.

Storativity - see Storage coefficient.

Superposition Principle - the addition or subtraction of two or more different solutions of a governing linear partial differential equation (PDE) to obtain a composite solution of the PDE. As an example, the superposition of drawdown caused by a pumping well on a regional, nonpumping potentiometric surface.

Transient Conditions - a condition in which system inputs and outputs are not in equilibrium so that there is a net change in the system with time.

Transient Flow - a condition that occurs when at any location in a groundwater or vadose zone flow system the magnitude and/or direction of the specific discharge changes with time.

Transmissivity - the volume of water at the existing kinetic viscosity that will move in a unit time under a unit hydraulic gradient through a unit width of the aquifer. It is the product of the hydraulic conductivity multiplied by the aquifer thickness.

Unsaturated Zone - the zone between the land surface and the water table which may include the capillary fringe. Water in this zone is generally under less than atmospheric pressure and some of the voids may contain air or other gases at atmospheric pressure. Beneath flooded areas or in perched water bodies the water pressure locally may be greater than atmospheric.

Vadose zone - see Unsaturated zone.

Vadose zone Flow System - an aggregate of rock, in which both water and air enters and moves and which is bounded by rock that does not allow any water movement, and by zones of interaction with the earth's surface, atmosphere and surface water systems. A vadose zone flow system has two basic hydraulic functions: it is a reservoir for water storage and it serves as a conduit by facilitating the transmission of water from intake to discharge areas, integrating various inputs and dampening and delaying the propagation of responses to those inputs. A vadose zone flow system may transport dissolved chemical constituents and heat.

Velocity, Darcian - See Specific Discharge.

Velocity, Average Interstitial - the average rate of groundwater flow to interstices expressed as the product of hydraulic conductivity and hydraulic gradient divided by the effective porosity. Synonymous with average linear groundwater velocity or effective velocity.

Water Mass Balance - an inventory of the difference source and sinks of water in a hydrogeologic system. In a well-posed model, the sources and sinks should balance.

Water table - the surface of a groundwater body at which the water pressure equals atmospheric pressure. Earth material below the groundwater table is saturated with water.

Zone of Saturation - A hydrologic zone in which all the interstices between particles of geologic material or all of the joints, fractures, or solution channels in a consolidated rock unit are filled with water under pressure greater than that of the atmosphere.

Appendix 2. Groundwater Modeling References

The following references are grouped into general categories related to modeling. This list is intended to provide background information to help you develop a better understanding of difference aspects of groundwater and fate and transport modeling. This reference list is not meant to be all-inclusive.

Boundary Conditions

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